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Link life time and energy-aware stable routing for MANETs

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Abstract

One of the major problems in mobile ad hoc networks (MANETs) routing is the short lifetime of their routes. This problem has roots in the network's dynamic topology and its nodes' limited battery capacity. One of the solutions to upgrade this routing scheme's efficiency is to select the most stable paths to reduce the latency and the overhead arising from the routes' reconstructions. This paper designs a routing protocol that calculates multiple stable paths between the source and the destination and then selects the best available path among them. The proposed protocol is based on the AODV protocol. Compared with previous works on AODV, this work has two significant improvements. First, it selects only node-disjoints paths, hence failure of one path doesn't affect other paths. Second, it selects high-quality stable routes using an efficient formula. Extensive simulations in the NS-2 environment show that the proposed protocol, ST-AODV (Stable Ad hoc On-demand Distance Vector) outperforms AODV regarding packet delivery ratio, end-to-end delay, routing frequency, and routing overhead.

Keywords: Mobile Ad hoc Networks, Routing, Stable routing, Energy-Aware Routing, AODV
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1 Introduction

Autonomous wireless and mobile nodes. Every node in a MANET act as both host and router [5, 12, 29]. A significant amount of research has been directed toward designing efficient dynamic routing protocols for MANETs. The challenge is reducing routing overheads despite the changing topology [4, 6, 24]. This is a critical issue because both link bandwidth and battery power are premium resources [1, 11, 13, 23, 25, 30].

A notable class of routing protocols in MANETs is on-demand protocols, such as dynamic source routing (DSR) [10], ad hoc on-demand distance vector (AODV) [20] and temporally ordered routing algorithm (TORA) [19]. On-demand protocols reduce routing overhead by maintaining routes only between nodes that take part in data communication. Specifically, whenever a traffic source needs a route to a destination, the protocol initiates a route discovery process. Route discovery typically involves the network-wide flood of a route request and waiting for a route reply [3, 5]. The on-demand approach is not without problems. Since routes are computed only on demand, route discovery latency can increase the end-to-end delay unless a previously computed cached route is available. Buffering of data packets during

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the route discovery process can also contribute to packet loss from buffer overflow. With single-path routing, this problem increases as the network becomes more dynamic. The frequency of route discoveries increases as the rate of link failure increases. Since each route discovery incurs substantial packet overhead, its frequency affects performance. Frequency can be controlled by computing multiple paths with a single route discovery. This will improve the overall performance [21].

In recent years, many works have focused on enhancing AODV performance [18, 27]. Ad hoc on-demand multipath distance vector (AOMDV) is a multipath version of AODV [16]. It is a basic multipath protocol of AODV that discovers all link disjoint routes and uses them for data forwarding. The routes discovered in AOMDV have shared nodes, thus, AOMDV failure of a route may affect other routes. SQR-AODV presented a stable QoS-aware reliable AODV; in this scheme, data is sent through a route with high stability [9]. AODV-BR presents a scheme to improve AODV by creating a mesh and providing multiple alternate routes [14]. They propose an algorithm that utilizes a mesh structure to provide multiple alternate paths to existing on-demand routing protocols without producing additional control messages. AODV-RD presents an AODV with reliable delivery [15]. This protocol is based on a link failure prediction mechanism with due consideration given to link status and improved AODV-BR combinations to achieve the full purpose of improving PDR. AOTMDV is a trust-based reactive multipath routing protocol proposed for MANETs [31]. This protocol is a flexible approach that chooses the shortest path and meets the security requirements of data packet transmission. AOMR-LM is another multipath routing scheme for routing in MANETs [26]. This protocol reserves the residual energy of nodes and helps to balance the consumed energy to increase the network lifetime. For this purpose, AOMR-LM uses the residual energy of nodes for calculating the node energy level. The multipath selection mechanism uses this energy level to classify the paths.

Stable routing in MANETs causes the lifetime of discovered routes to be long, this increases network efficiency [22]. This study develops a stable protocol for routing in MANETs on the framework of AODV. In comparison with previous works on AODV, this work has two significant improvements. First, it selects only node-disjoints paths, hence failure of one path doesn't affect other paths. Second, it selects high-quality stable routes using an efficient formula. The novelty of this paper is that it performs stable routing for routing in mobile ad hoc networks and performs stable routing by considering both energy and link lifetime.

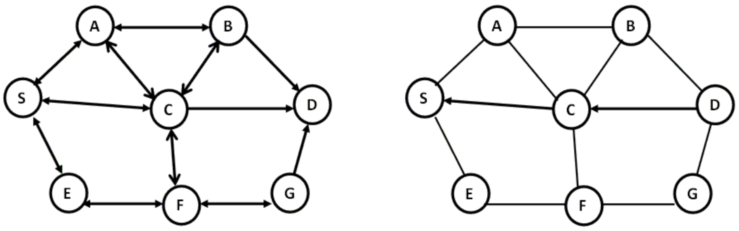
The rest of the paper is organized as follows. An overview of the AODV protocol is presented in the next section. Section 3 presents the ST-AODV protocol. The performance of ST-AODV is measured in Section 4 using the results of a widespread experiment. The conclusion is presented in Section 5.

2 AODV: Ad hoc On-demand Distance Vector

AODV is a distance-vector routing for mobile ad-hoc networks. The protocol consists of two phases: route discovery and route maintenance. When a traffic source needs a route to a destination, it initiates a route discovery process. Route discovery typically involves a network-wide flood of a route request (RREQ) for a destination and waiting for a route reply (RREP). Duplicate copies of an RREQ at every intermediate node are discarded. A source attaches a strictly increasing broadcast ID with each RREQ it generates. The source ID and the broadcast ID of the RREQ are used to detect duplicates. Every time a new discovery process is initiated, the broadcast ID one increases. An intermediate node receiving a non-duplicate RREQ first sets up a reverse path to the source using the previous hop of the RREQ as the next hop on the reverse path. If a valid route is available, then the intermediate node generates an RREP, otherwise, the RREQ is rebroadcast. When the destination receives a non-duplicate RREQ for itself, it generates a RREP. The RREP is routed back to the source via the reverse path. As the RREP proceeds towards the source, a forward path to the destination is established [30]. The second phase of the protocol is called route maintenance. It is performed by the source node and can be subdivided into:

- When the source node moves and its connection with the next node disconnects, it restarts the route discovery process.
- When the destination or intermediate node breaks, a route error message (RERR) is sent to the source node.

Intermediate nodes receiving a RERR update their routing table by setting the distance of the destination to infinity. If the source node receives a RERR it will initiate a new route discovery. To prevent global broadcast messages, AODV introduces local connectivity management. This is done by periodical exchanges of HELLO messages, which are small RREP packets containing a node's address and additional information. AODV combines the use of destination sequence numbers as in DSDV with the on-demand route discovery technique in DSR to formulate a loop-free, on-demand, single path, distance vector protocol. In contrast to DSR, AODV uses hop-by-hop routing instead



a) RREQ flooding **b) RREP transmission**

Figure 1: Route discovery process in AODV

of source routing [30]. Fig. 1 shows the route discovery process by AODV. In this figure, node S is the source node and node D is the destination node. Fig. 1(a) shows the flooding of the RREQ packet and Fig. 1(b) shows the transmission of the RREP packet. One route is established between the source and destination; the discovered route is SCD.

3 ST-AODV Routing Protocol

In this section, we present the ST-AODV protocol which is a stable routing protocol to discover and use stable and high-efficiency paths. In this protocol, the link lifetime, the length of paths, and the level of route nodes' energy should be considered. In the route discovery process, the metrics of a route that can be assessed by its stability are longevity and nodes' energy along the path [2]. The link lifetime parameter identifies the length of the link e that exists between two nodes and the energy parameter specifies for how long the node will be on [7, 17]. These two parameters are basic factors in the stability of a route; applying them to the AODV protocol leads to ST-AODV, which is a stable multi-path routing protocol.

Link lifetime: The link lifetime existing between two mobile nodes depends on factors such as node movement speed, node movement direction, node location, and node transfer range [9].

Node energy: In this protocol, node energy is a percent of the residual energy of the nodes. To obtain the remaining energy of a node, its primary and current energy must be calculated. The remaining energy of the node is then divided into the initial energy of the node to gain the Node energy.

Now, we can bring details of our routing protocol. To discover and use stable routes while sending an RREQ from a source to a destination node, the minimum amount of node energy and the minimum and maximum link lifetime of each route should be found and sent to the destination node inside the RREQ packets. For this purpose, three new fields are added to the RREQ:

$\min_{llt}$ field: the shortest link lifetime from the source to the current node.

$\max_{llt}$ field: the longest link lifetime from the source to the current node.

$\min_{energy}$ field: the lowest node energy from the source to the current node.

In order to set values for added fields, a neighbor which receives RREQ from a source node adds the energy and links the lifetime between a source node and itself to the RREQ packet, and sends it to its neighbors. The next neighbor receives the RREQ packet and compares its energy with the $\min_{energy}$ field located in the RREQ packet. If it is less thanmin$_{energy}$, it will set its energy as the least energy from the source to the destination node in the $\min_{energy}$ field. The RREQ packet which receives the node calculates the link lifetime between itself and the former node and compares it with the $\min_{llt}$ ($\max_{llt}$) field located in the request packet. If the lifetime is less (greater) than $\min_{llt}$ ($\max_{llt}$) field, the value will be set as the minimum (maximum) link l lifetime from the source to the current node in the $\min_{llt}$ ($\max_{llt}$) field. In this way, when the RREQ packet reaches the destination node, the shortest (highest) lifetime of the link is in $\min_{llt}$ ($\max_{llt}$) field, the minimum path energy is in the $\min_{energy}$ field and the path length is in the hop count field. After reaching the destination node uses formula 1 and the destination node assesses the path stability and efficiency [26, 31]:

$$\text{Routequality} = \frac{\min_{\text{energy}} +(((\min_{llt})/\max_{\text{lltbetweenallroutes})\times 2)}}{(\text{Hopcount}/(\text{MaximunHopcountbetweenroutes}))}. \tag{3.1}$$

Because the efficiency of the route has a direct relationship with link lifetime and energy of node, and also the efficiency of the route has a vice versa relationship with route hop count, therefore we use formula (3.1) for obtaining

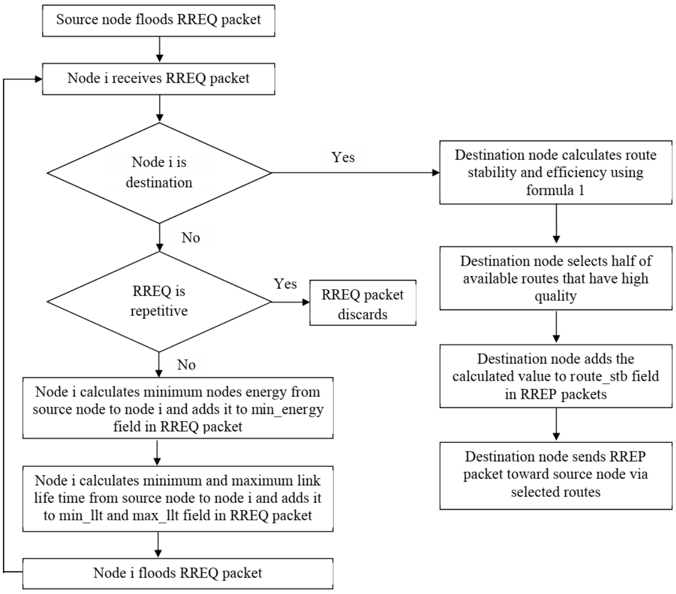


Figure 2: ST-AODV Route discovery flow chart

routes quality. The destination node compares route quality between all routes and selects half of the available routes that have high quality. The obtained value from formula (3.1) shows the path stability and efficiency. It is added as a new field called route_stb field in the RREP packet.

When the RREP packet arrives at the source node and the paths are discovered, the source node uses the paths to send data that has the highest stability; it means the route_stb related to that path is higher than other paths. If the highest stability is equal to more than one path, the data will be sent to the path that has the shortest path length. In the ST-AODV protocol, stable routes will be discovered and the most stable path will be used to send the data. If the primary path breaks, other discovered paths can be used instead of doing a new route discovery process. In Fig. 2, the ST-AODV route discovery process is shown. Note that in this flow chart, major operations of ST-AODV are shown and details of AODV have not been shown.

4 Performance evaluation

To evaluate the effects of the proposed protocol, simulations were carried out in the Ns-2 [28] simulator environment. To implement the ST-AODV protocol, changes were made in the Ns-2 simulator environment for the AODV protocol. The ST-AODV and AODV protocols in the form of different scenarios were compared based on the following efficiency criteria:

Packet delivery ratio: the ratio of data packets delivered to destination to data packets sent from source [8].

End-to-end delay: the average time for each packet as the benchmark against which the source node reaches the destination node [8]. The end-to-end delay unit is second. Route discovery frequency: the benchmark average number of the route discovery process that each data packet delivers to the destination [3].

Routing overhead: the total number of times the measure of routing packets sent out on the network [3].

Two simulation scenarios were considered to compare the efficiency of ST-AODV with the AODV. In the first scenario, the numbers of the nodes considered were variables to evaluate the scalability of the protocol during node changes. In the second scenario, the rate of packet sending was considered to be variable to evaluate the protocols under different traffic and data conditions. The common parameters are: simulation done in a space of 1000 m in 1000 m; data packets 512 bytes in size are sent between nodes; the movement model of nodes is based on the random waypoint mobility pattern of nodes; the initial energy of all nodes is 40 j and uses the IEEE 802.11 standard as the medium access protocol. The line interface used in the priority queue is a 50-packet drop-tail and the maximum speed of nodes is 20 m/s. The transmission range of nodes is 250 m. We generate nodes' positions and data traffic among nodes randomly.

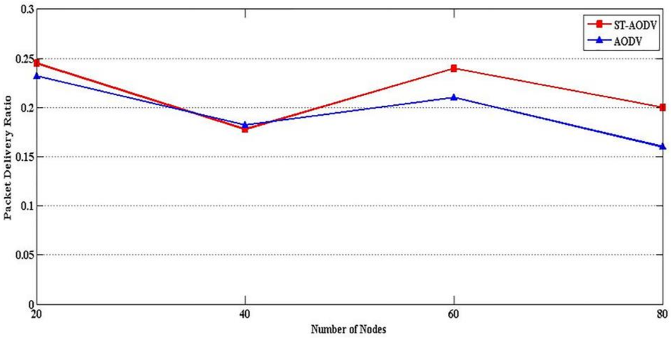


Figure 3: Packet delivery ratio per number of nodes

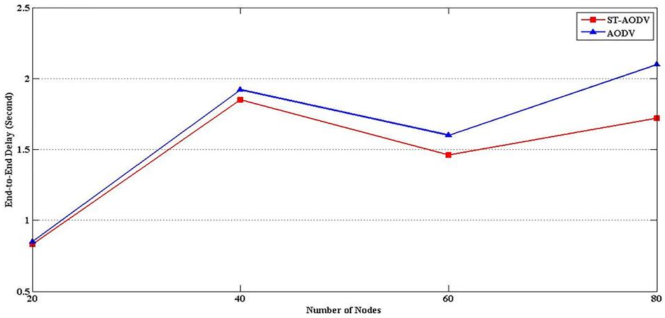


Figure 4: End-to-end delay per number of nodes

4.1 Scenario 1: Efficiency per number of nodes

In this simulation, the numbers of the nodes considered were variables to evaluate the scalability of the protocol during node changes. The variable parameter is the number of nodes such as 20, 40, 60, and 80 and the data packets are sent at a rate of 10 packets per second. Every scenario simulated with variable nodes uses ST-AODV and AODV in 1000 seconds. The results of the simulations are shown in Figs. 3 to 6. As shown in these figures for this parameter, ST-AODV shows better performance than AODV, because the ST-AODV protocol selects the most stable paths at any route discovery of the network due to considering link lifetime and energy in addition to a hop count.

4.2 Scenario 2: Efficiency per traffic rate

In this simulation, the rate of packet sending was considered to be variable to evaluate the protocols under different traffic and data conditions. There are 50 mobile nodes in this scenario with variable rates of sending data between these nodes. The rate was 5, 10, and 15 packets per second respectively. A mobility pattern for the nodes was produced with a pause time of 100 s. The scenarios simulated use ST-AODV and AODV for 1000 s. The averages of the results

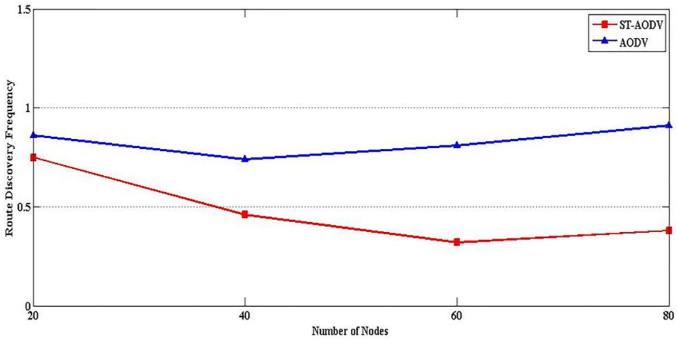


Figure 5: Route frequency process per number of nodes

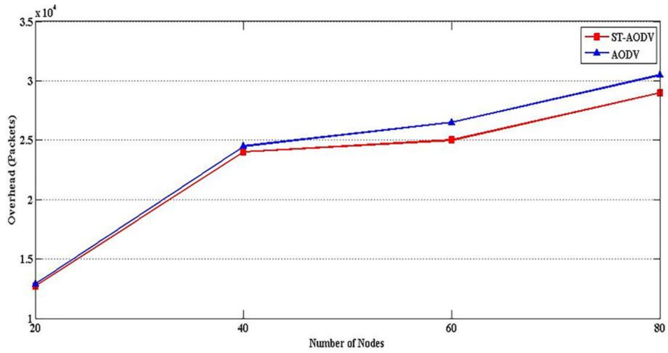


Figure 6: Routing overhead per number of nodes

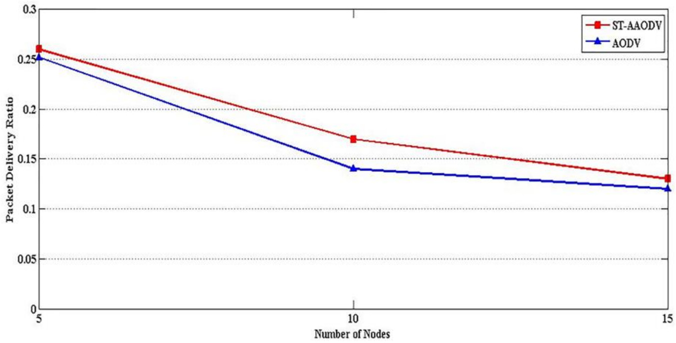


Figure 7: Packet delivery ratio per traffic rate

are shown in Figs. 7 to 10. They show that the exchange rate of the data packet protocols provided by ST-AODV, in comparison with AODV has good performance.

As shown above, in any two conditions for all the throughput parameters, the ST-AODV protocol has a better performance compared to the AODV protocol. The reason for the better performance of ST-AODV is that it discovers stable routes and uses them there. For this reason, the data packets are transferred from reliable routes. Because of path failure from the multipath protocol ST-AODV and backup paths, there was no need for rerouting, this caused the routing overhead and latency to decrease. Therefore the efficiency of ST-AODV increased.

5 Conclusion

This paper presented the ST-AODV protocol. It is based on the AODV routing protocol. This protocol finds multiple node-disjoint paths and selects the final choice based on the link lifetime and the remaining node's energy. These parameters are major factors in path stability. In this way, our protocol uses stable node-disjoint paths for data

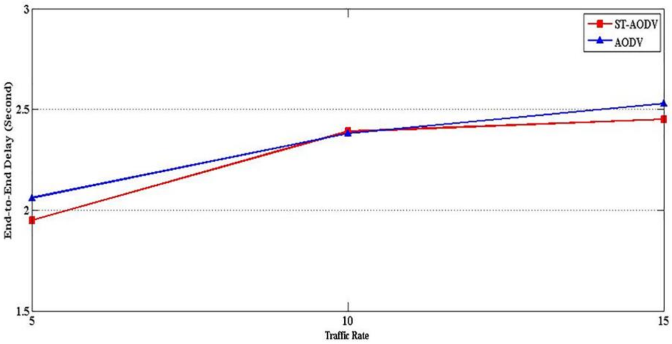


Figure 8: End-to-end delay per traffic rate

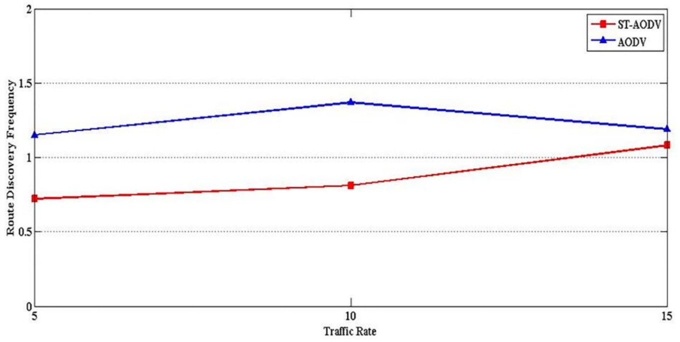


Figure 9: Route frequency process per traffic rate

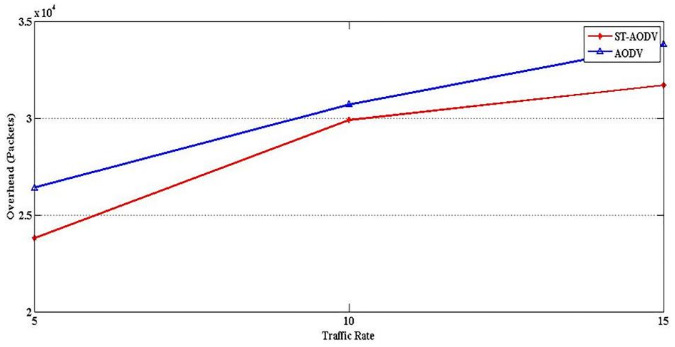


Figure 10: Routing overhead per traffic rate

transmission. As a result, ST-AODV is a stable multipath routing protocol and reduces the need for frequent routing. Simulation results in Figs. 3 to 10 indicate that ST-AODV performs better than AODV in terms of packet delivery ratio, end-to-end delay, routing frequency, and routing overhead.

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